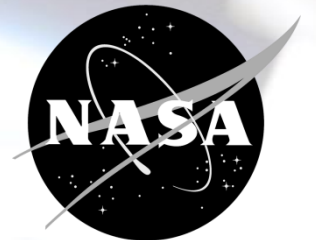


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# In situ Resource Utilization: How to Live and Thrive in Space

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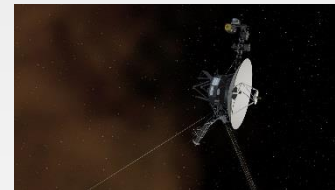
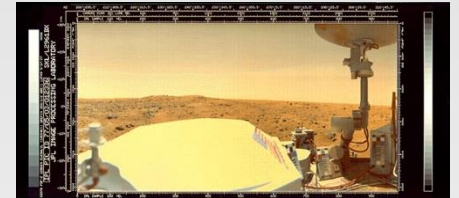
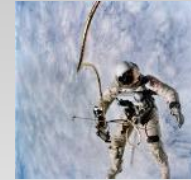
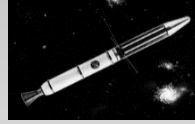
Paul E. Hintze, Ph.D.  
NASA Kennedy Space Center  
[Paul.E.Hintze@nasa.gov](mailto:Paul.E.Hintze@nasa.gov)



# Significant Events in Space



- ❑ First American Satellite – 1958
- ❑ First American to Orbit Earth – 1962
- ❑ First American Spacewalk – 1965
- ❑ First Manned Lunar Landing – 1969
- ❑ First Robotic Landing on Mars – 1971
- ❑ Space Shuttle Flights – 1981-2011
- ❑ Continuous human occupation of space – 2000 - present
- ❑ First Spacecraft to Leave the Solar System – 2013-2014



# Significant Events in Space



**HUMAN EXPLORATION**  
*NASA's Path to Mars*

**EARTH RELIANT**  
MISSION: 6 TO 12 MONTHS  
RETURN TO EARTH: HOURS

**PROVING GROUND**  
MISSION: 1 TO 12 MONTHS  
RETURN TO EARTH: DAYS

**MARS READY**  
MISSION: 2 TO 3 YEARS  
RETURN TO EARTH: MONTHS

Mastering fundamentals aboard the International Space Station

U.S. companies provide access to low-Earth orbit

Expanding capabilities by visiting an asteroid redirected to a lunar distant retrograde orbit

The next step: traveling beyond low-Earth orbit with the Space Launch System rocket and Orion spacecraft

Developing planetary independence by exploring Mars, its moons and other deep space destinations

[www.nasa.gov](http://www.nasa.gov)

The infographic is set against a dark space background with stars. It features illustrations of the International Space Station, a rocket launching from Earth, a spacecraft orbiting the Moon, a spacecraft visiting an asteroid, and a spacecraft approaching Mars. The NASA logo is in the top right corner.



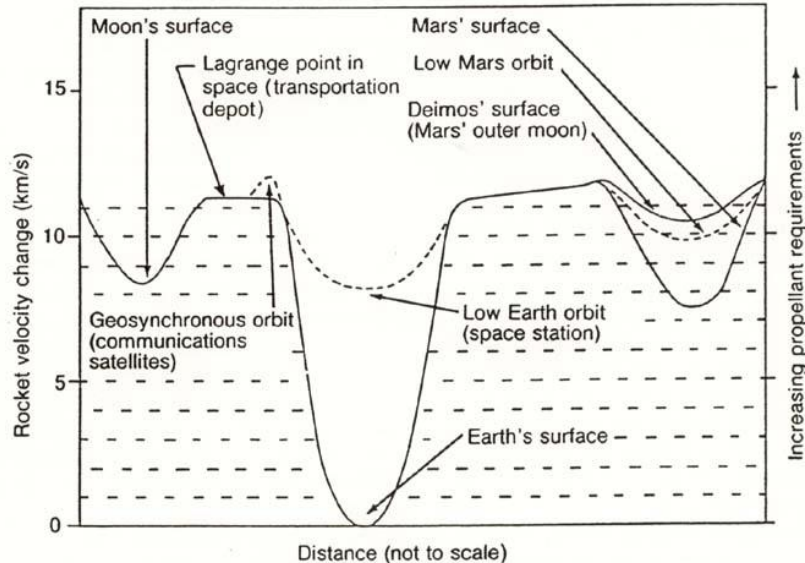
# Gravity Wells and Gear Ratios



Figure 1

## The Gravity Well of the Earth

The Earth sits in a deep gravity well and considerable rocket energy is necessary to lift material from that well and put it into space. The rocket velocity change ( $\Delta V$ ) shown here is an indication of the minimum fuel needed to travel to low Earth orbit and to other places, including the lunar surface and Deimos. Not shown on the diagram but also important is the fact that it takes less  $\Delta V$  to reach some Earth-crossing asteroids than it does to reach the lunar surface, about 10 percent less for asteroid 1982 DB, for example. This diagram is not a potential energy diagram, as the  $\Delta V$  depends on the path taken as well as the potential energy difference. However, it is a good indication of the relative fuel requirements of transportation from one place to another. The diagram also does not take into account travel times corresponding to minimum  $\Delta V$  trajectories. One-way travel times range from less than an hour to low Earth orbit to 3 days for lunar orbit to months to a year or more for Mars and Earth-crossing asteroids.

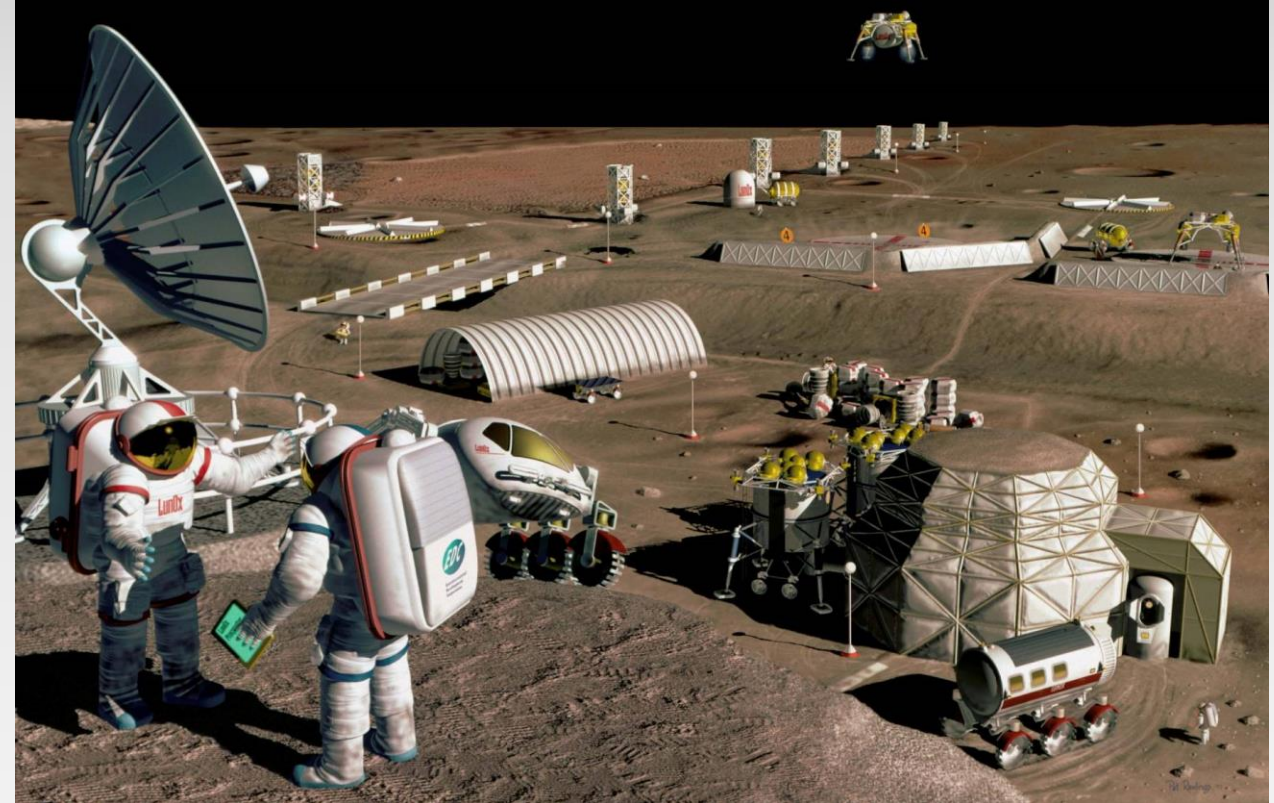


- ❑ NASA SLS will weigh 30,000 metric tons and deliver 130 metric tons to Low Earth Orbit (LEO)
- ❑ 20:1 gear ratio going from LEO to Mars surface
- ❑ One SLS launch can send 6.5 metric tons to Mars surface
- ❑ Proposed need of 5.8 metric tons of methane for return trip from Mars

# Introduction to ISRU



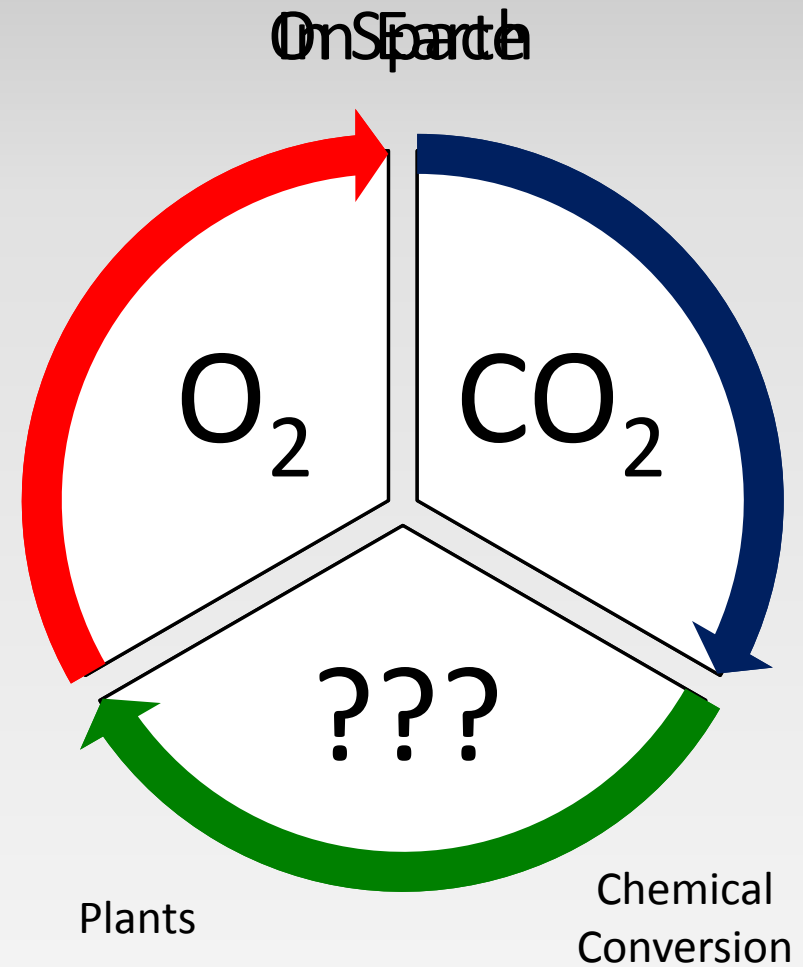
- ☐ **What is ISRU? – In Situ Resource Utilization**
  - ☐ “Living off the land”
  - ☐ Use Space Resources to reduce cost and risk for NASA missions
  - ☐ Already used with Solar Panels for power
- ☐ **What do we need?**
  - ☐ Life Support: Air, water, food
  - ☐ Propellant
  - ☐ Structures
- ☐ **Key space resources:**
  - ☐ Lunar regolith and polar water ice/volatiles
  - ☐ Asteroid regolith, metals, and volatiles
  - ☐ Martian atmosphere and water ice/hydrates



# Introduction to ISRU



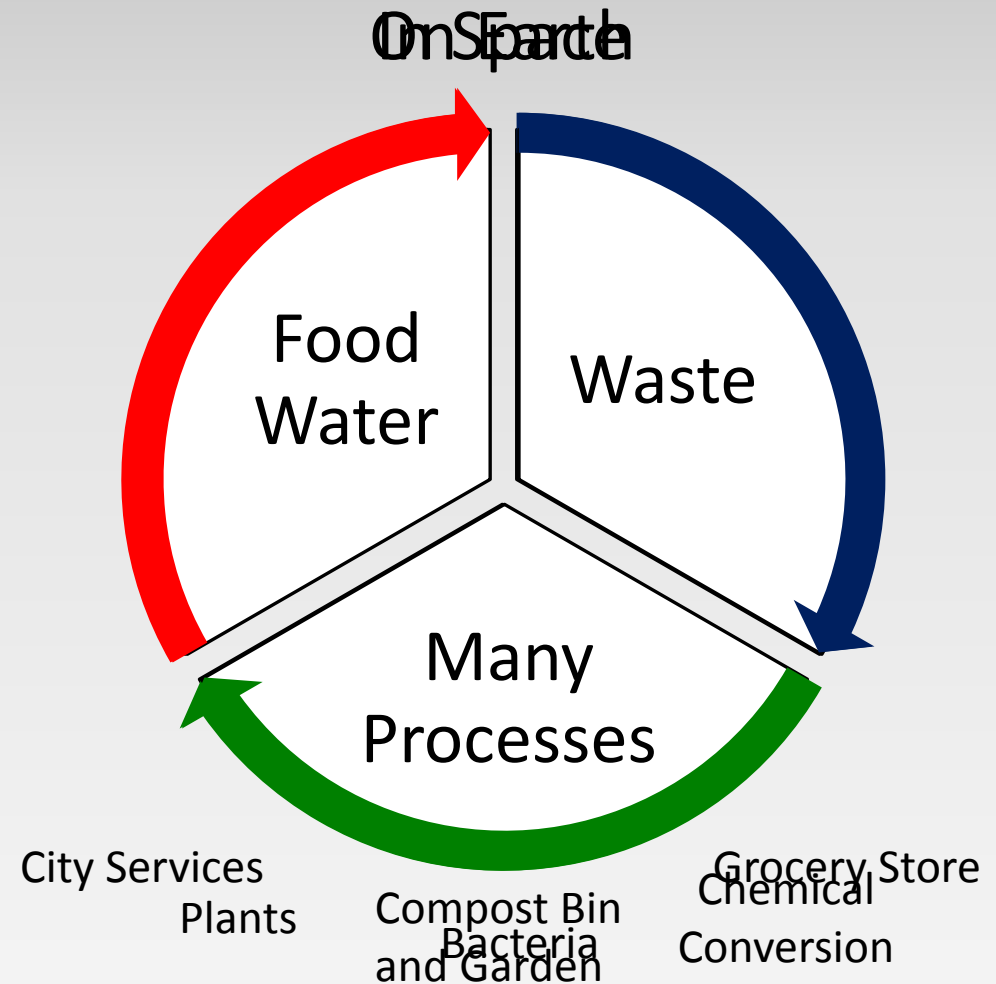
- What do we need?  
We need to breathe



# Introduction to ISRU



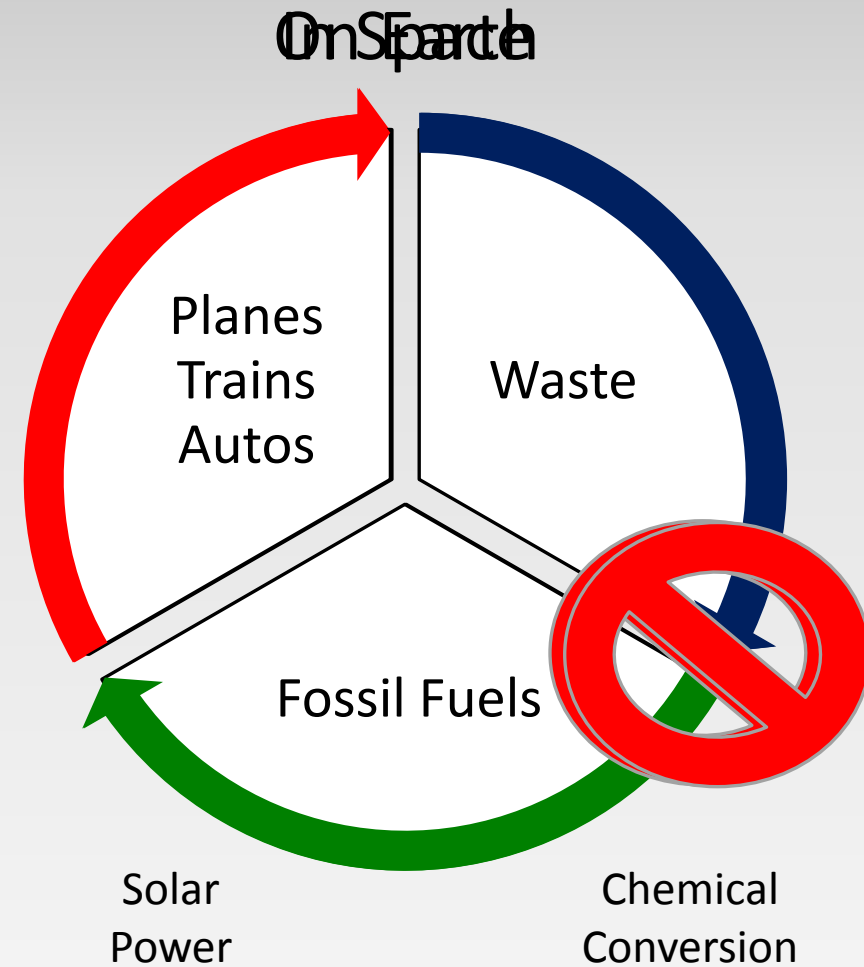
- What do we need?  
We need to eat/drink



# Introduction to ISRU



- ❑ What do we need?  
Transportation

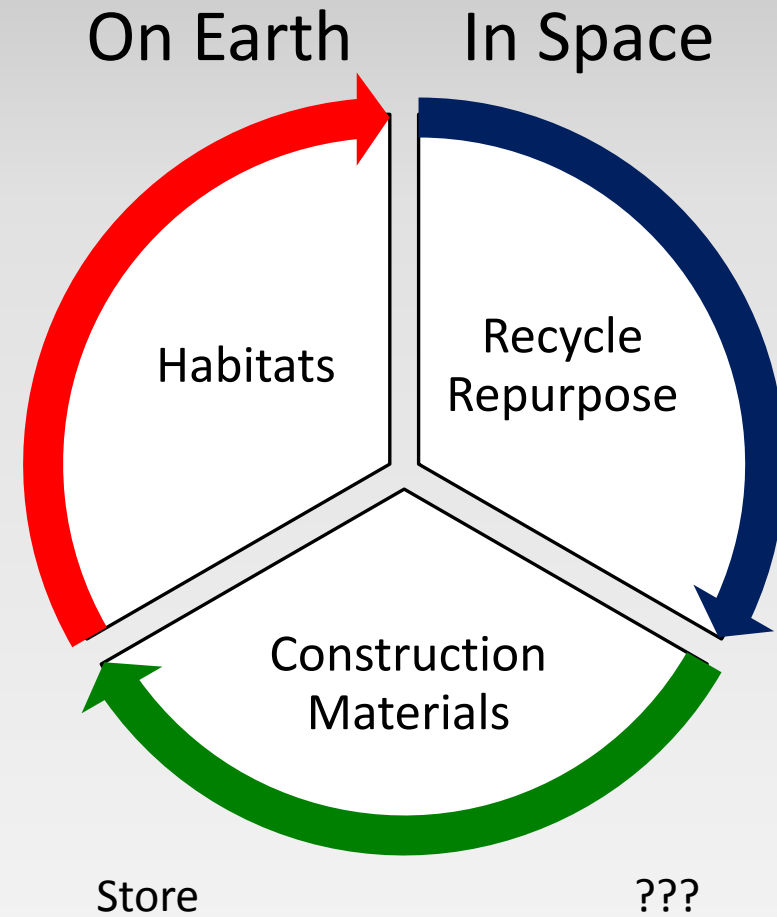




# Introduction to ISRU



□ What do we need?  
Shelter



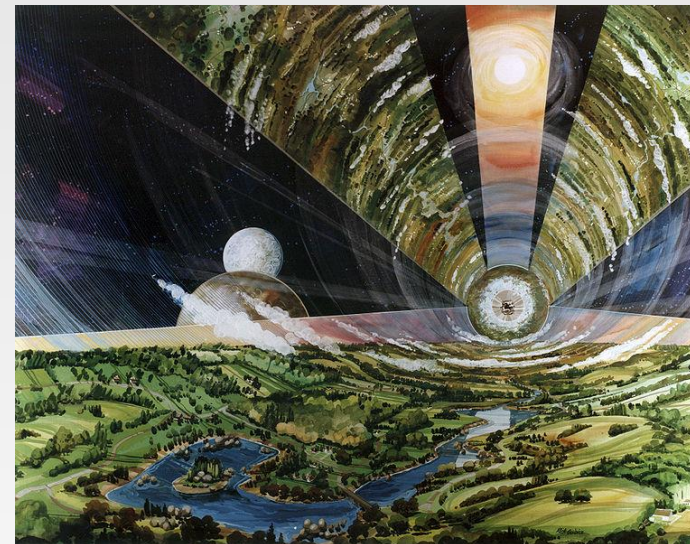
# ISRU in Books and Pop Culture



- ❑ The High Frontier, Gerard K. O'Neill, 1977
- ❑ The Case for Mars, Robert Zubrin, 1996
- ❑ Runaround, Isaac Asimov, 1942
- ❑ The Moon is a Harsh Mistress, Robert Heinlein, 1966
- ❑ Total Recall, 1990, based on "We Can Remember it for you Wholesale", Phillip K. Dick, 1966
- ❑ Interstellar, 2014
- ❑ The Martian, 2015



Mass driver on the moon



O'Neill cylinder

# ISRU Businesses



❑ Planetary Resources: asteroid mining, \$1.5 million crowd sourced for asteroid telescope. [www.planetaryresources.com/](http://www.planetaryresources.com/)

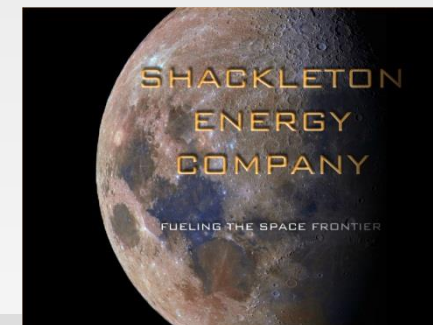


❑ Golden spike - monetize exploration of the moon. [goldenspikecompany.com/](http://goldenspikecompany.com/)

❑ Moon Express – mine moon for rare metals. [www.moonexpress.com/](http://www.moonexpress.com/)



❑ Shackleton Energy – mine water on moon for propellant. [www.shackletonenergy.com/](http://www.shackletonenergy.com/)



# ISRU – Earth's moon

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James Irwin, Apollo 15

☐ All needs brought from Earth



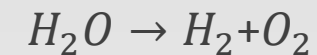
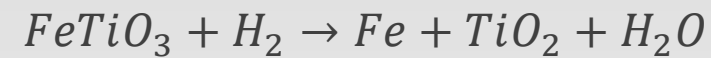
# ISRU – Earth's moon – Before 2009



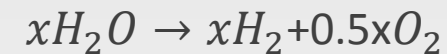
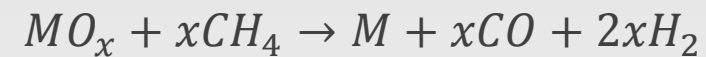
Lunar Regolith (soil)

- ❑ Needs come from regolith

- ❑ Hydrogen reduction:



- ❑ Carbothermal reduction



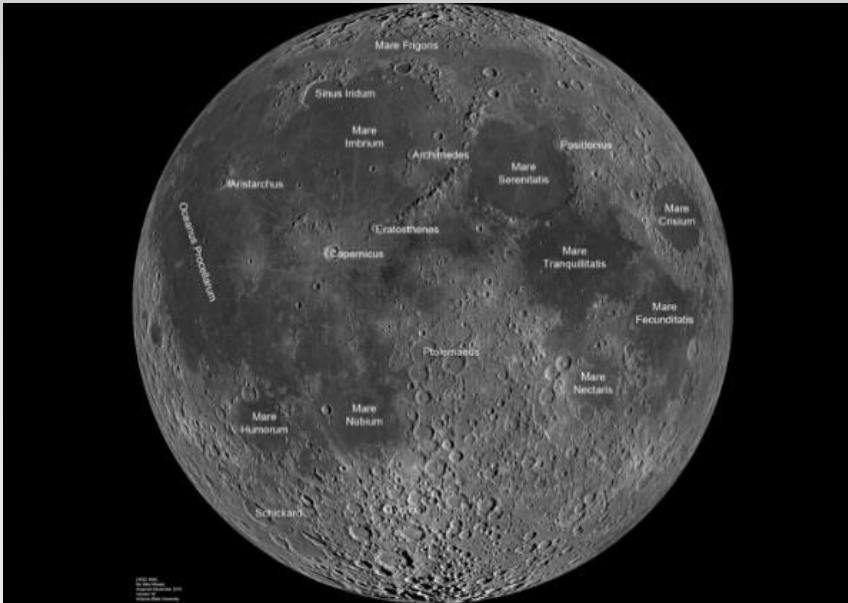
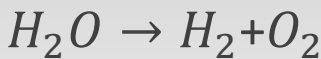
- ❑ Molten regolith electrolysis



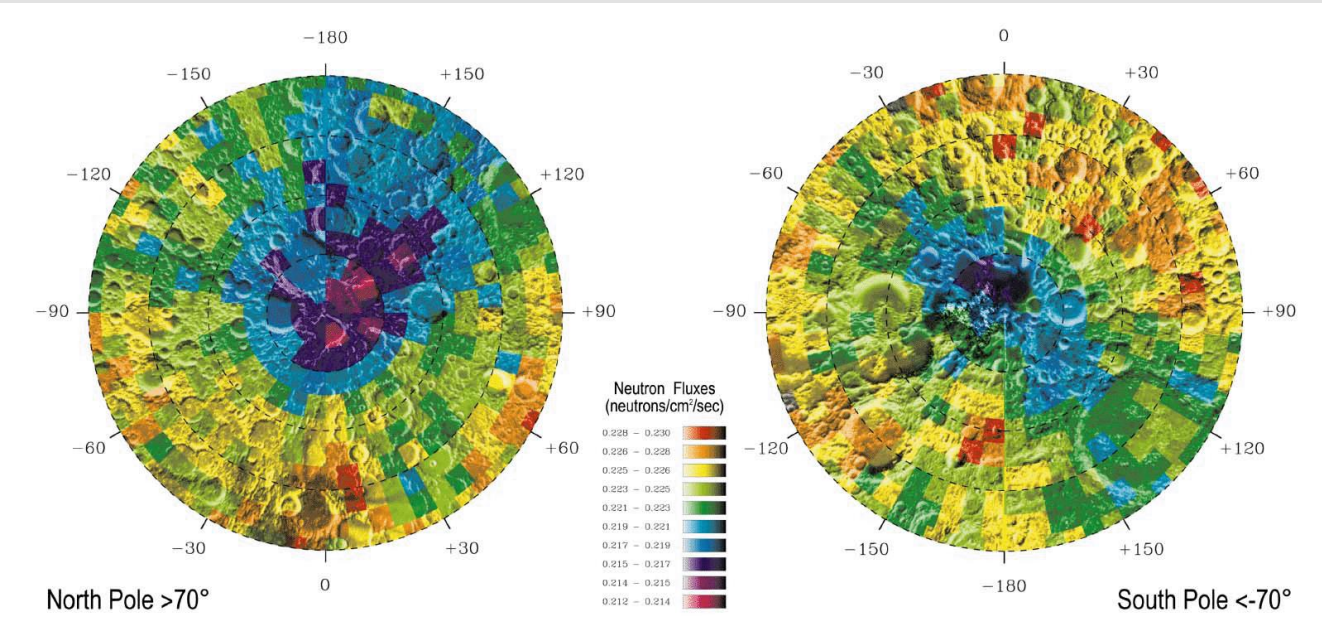


# ISRU – Earth’s moon – After 2009

☐ Water was discovered in 2009

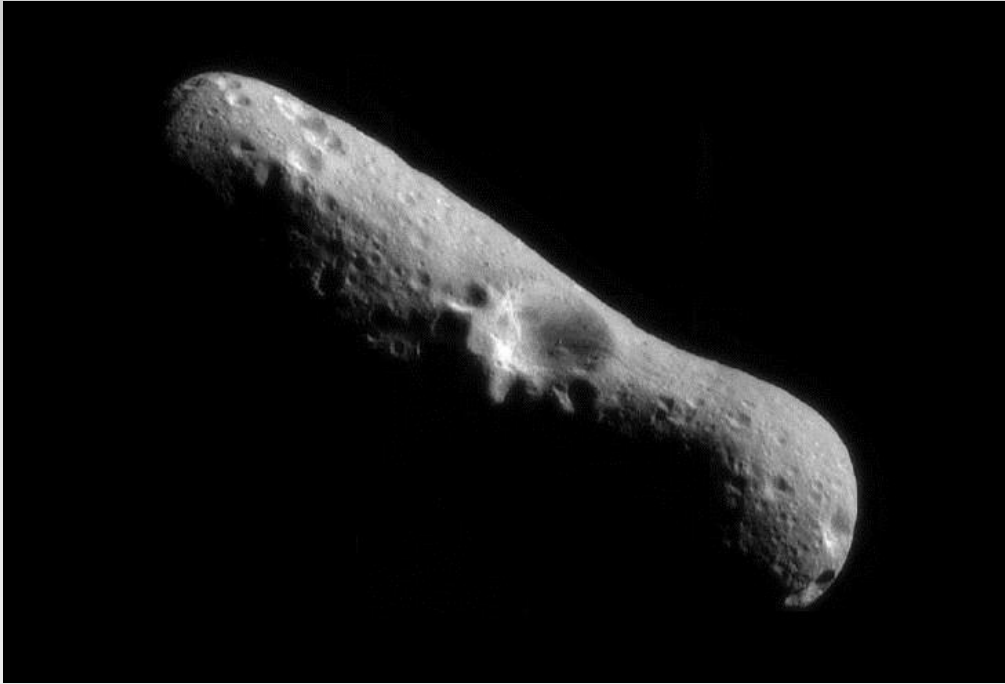


Lunar nearside mosaic  
taken by Lunar  
Reconnaissance Orbiter



Lunar Prospector Neutron Spectrometer

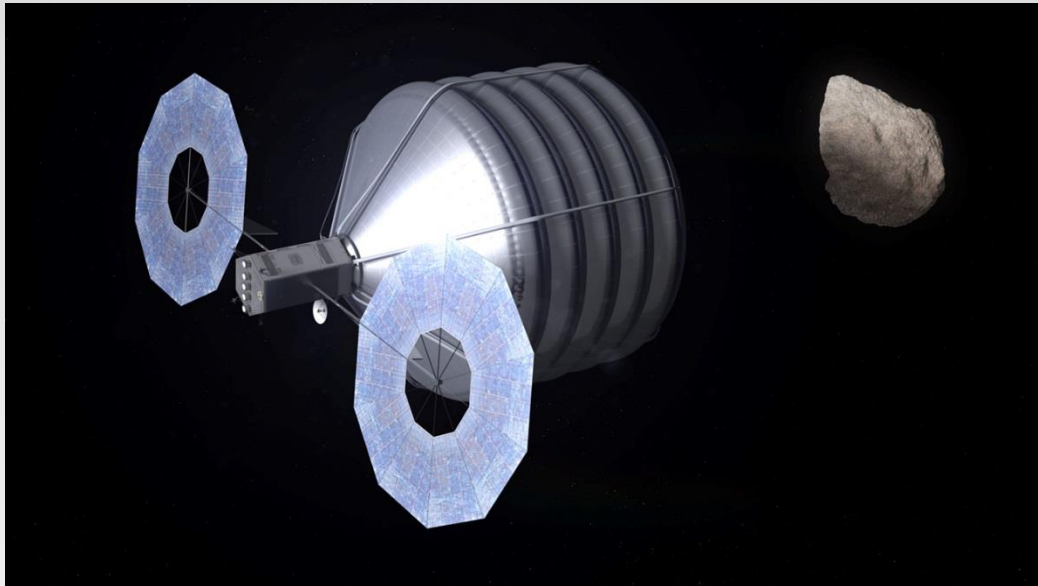
# ISRU – Asteroids



Eros, the first asteroid to have its picture taken by an orbiting craft in 2000 by NASA's NEAR mission

- ☐ Many classes of asteroids
- ☐ Metals (Ni, Fe, Pt, ???)
- ☐ Water
- ☐ Hydrocarbons
- ☐ Keck Asteroid Retrieval Feasibility Study recommends a carbonaceous C-type asteroid, containing up to 40% volatiles
- ☐ Produce fuel and structures
  - ☐ Heat shields
  - ☐ Turn an asteroid into a spacecraft!

# ISRU – Asteroids

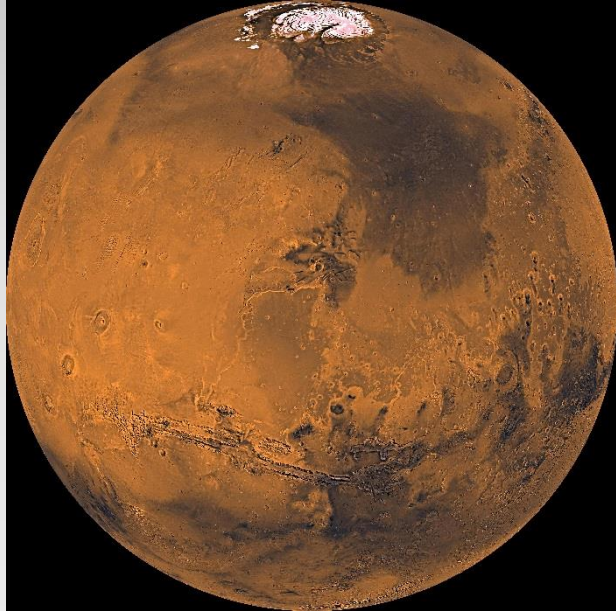


Concept for NASA's Asteroid Redirect Mission:  
Robotic vehicle capturing an asteroid



Concept for NASA's Asteroid Redirect Mission:  
Astronaut collecting samples

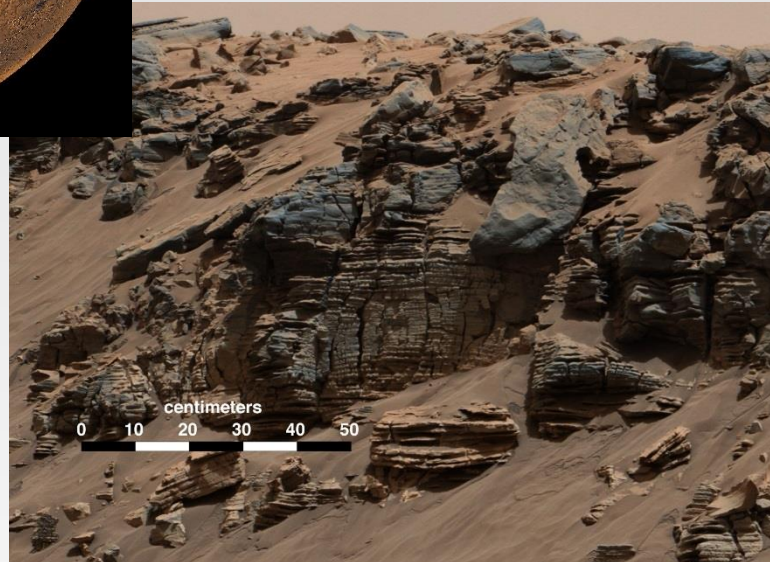
# ISRU – Mars



Mosaic of Mars  
taken during the  
Viking mission

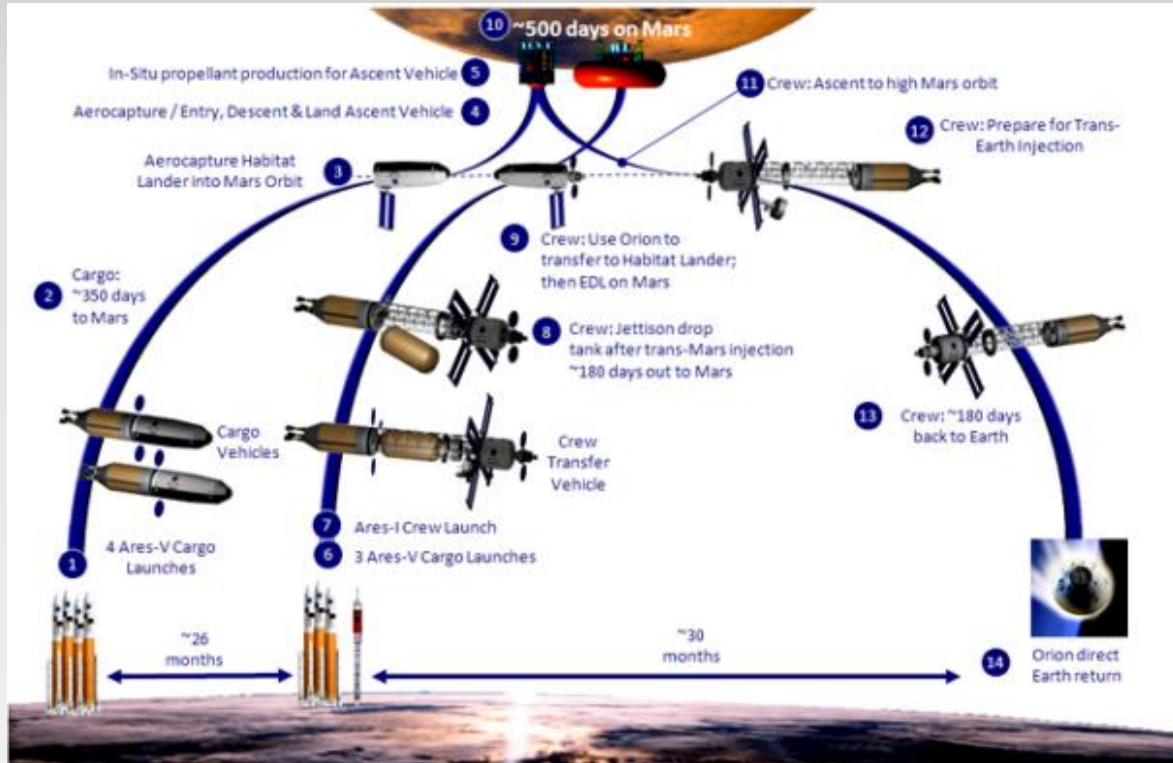
- ☐ Atmosphere of Mars
  - ☐ 96% CO<sub>2</sub>; 2% Ar; 2% N<sub>2</sub>
  - ☐ ~7 mbar (<1% Earth pressure)
- ☐ Water ice at poles, and up to 10% in the top meter of regolith

Sedimentary rocks  
taken by NASA's  
curiosity rover

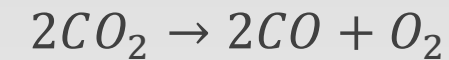




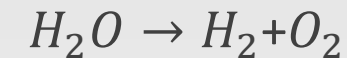
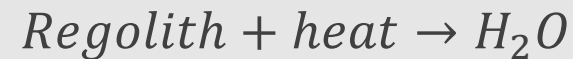
# ISRU – Mars



- ISRU: Atmosphere only; solid oxide electrolysis



- ISRU: Atmosphere and soil processing







# MARCO POLO: Mars Atmosphere and Regolith Collector/PrOcessor for Lander Operations

Oven

$\text{Regolith} + \text{heat} \rightarrow \text{H}_2\text{O}$

Electrolysis unit

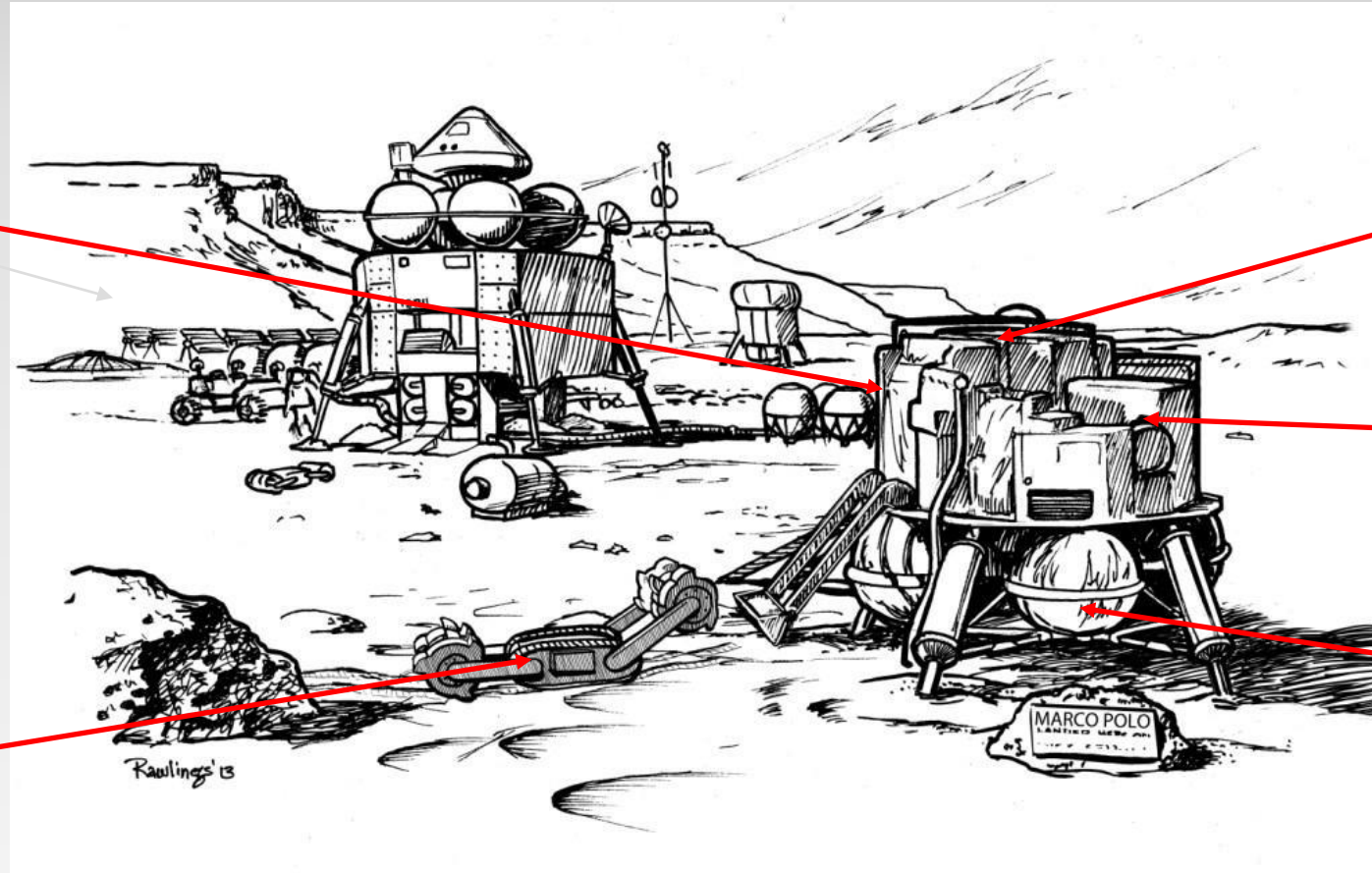
$\text{H}_2\text{O} \rightarrow \text{H}_2 + \text{O}_2$

Atmospheric Processing  
Module (APM)

$\text{CO}_2 + 4\text{H}_2 \rightarrow \text{CH}_4 + 2\text{H}_2\text{O}$

Rover collecting  
regolith

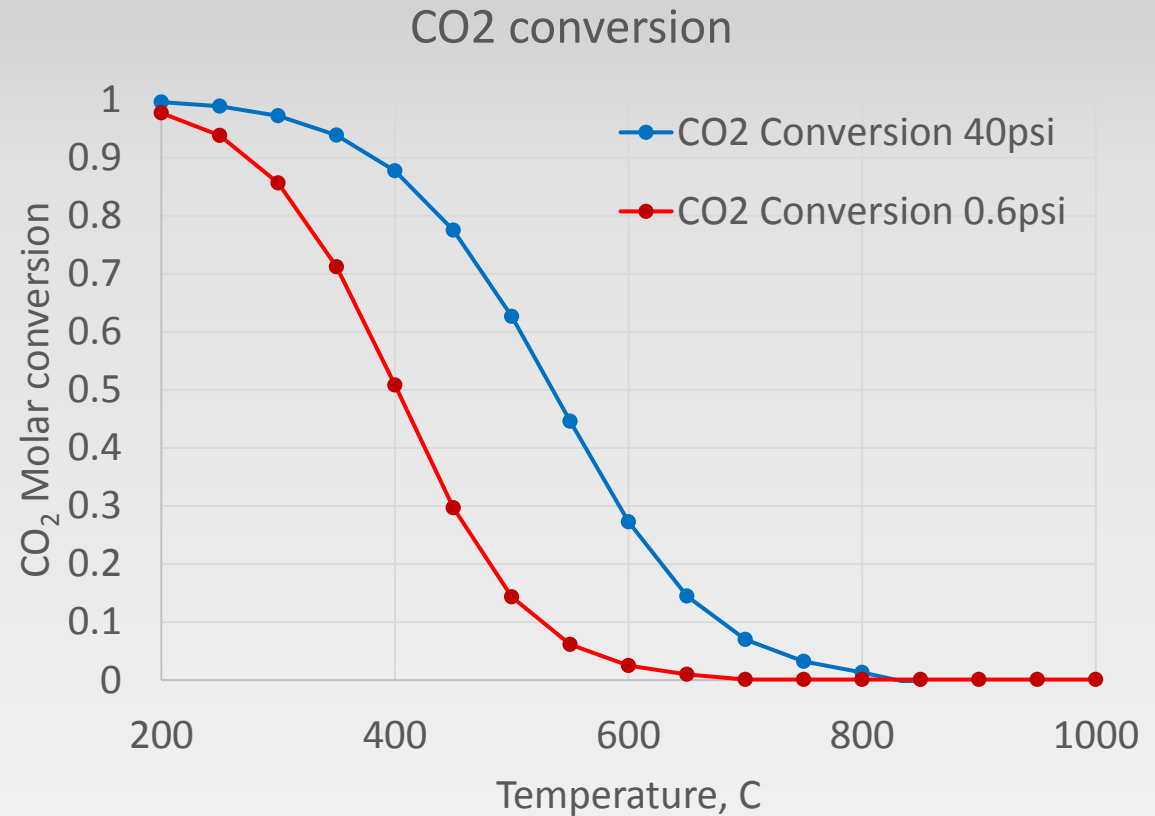
Fuel storage



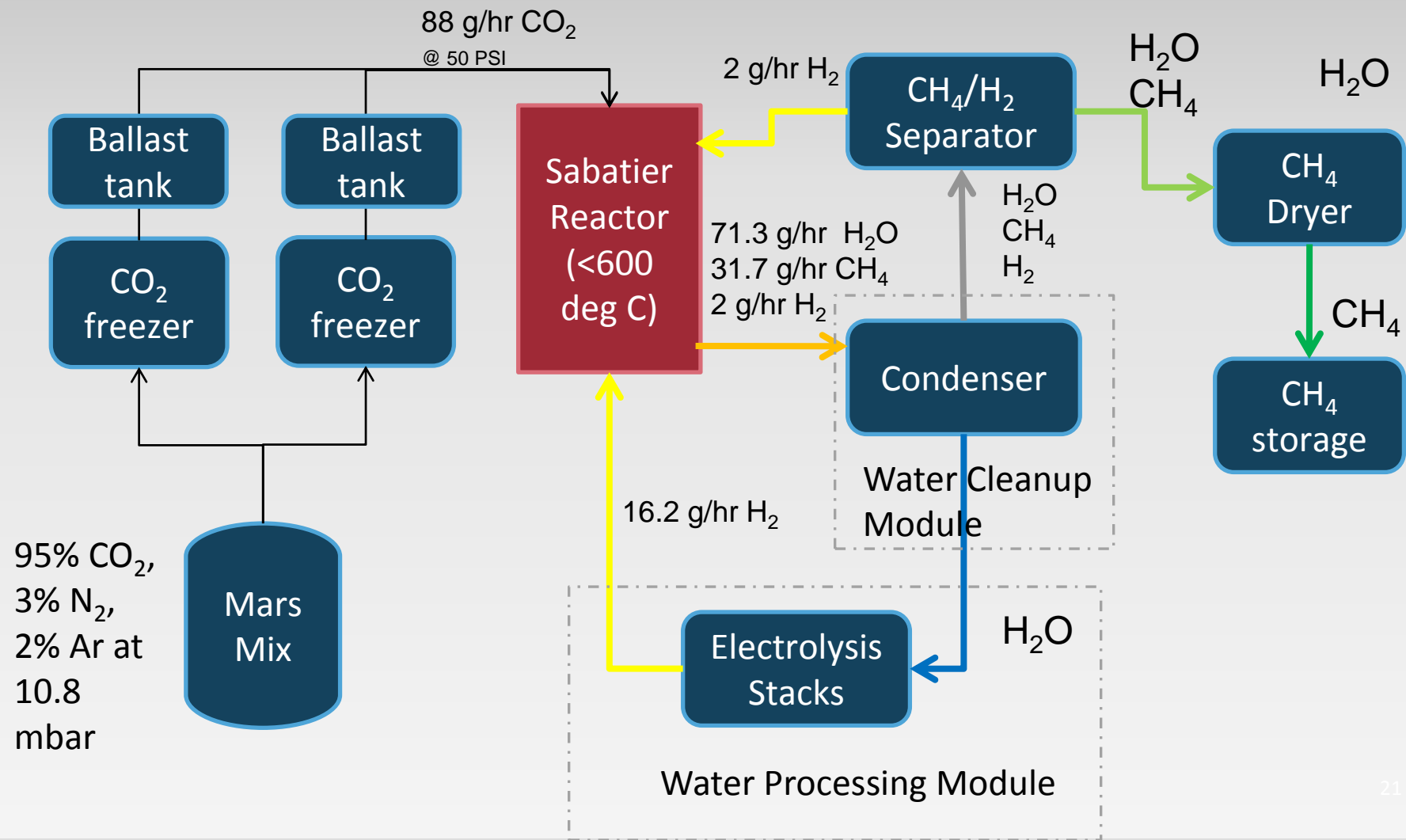
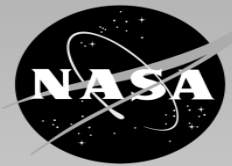
# MARCO POLO: APM



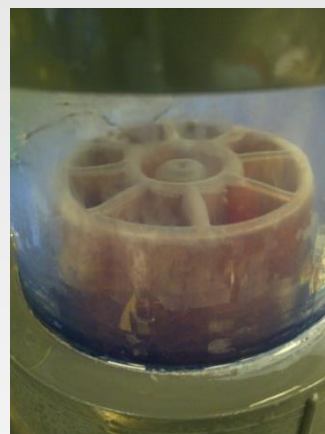
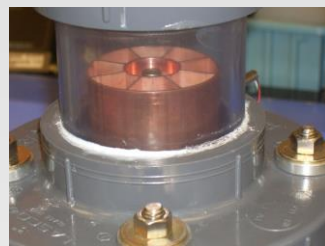
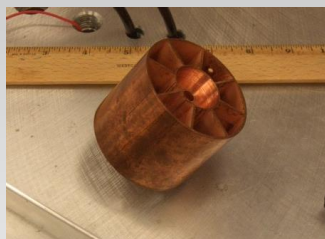
- ☐  $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$
- ☐ Why is this challenging?
  - ☐ Conversion to methane not as favorable at Mars atmospheric pressure
  - ☐ Methane production rate low if carbon dioxide is not compressed
  - ☐ Thermal management



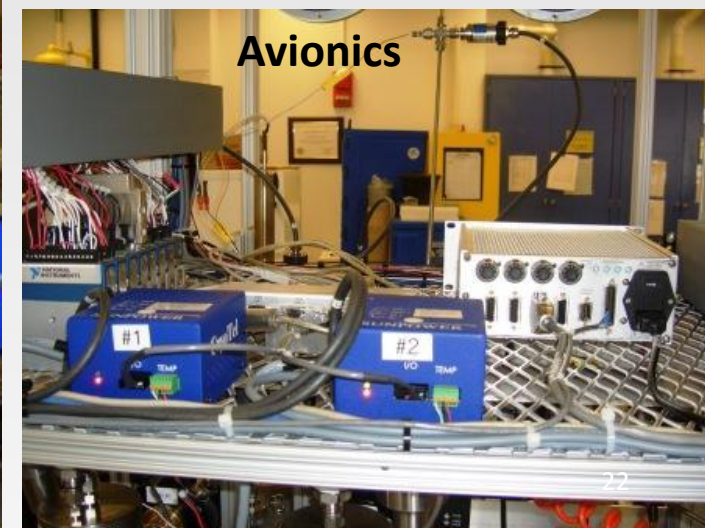
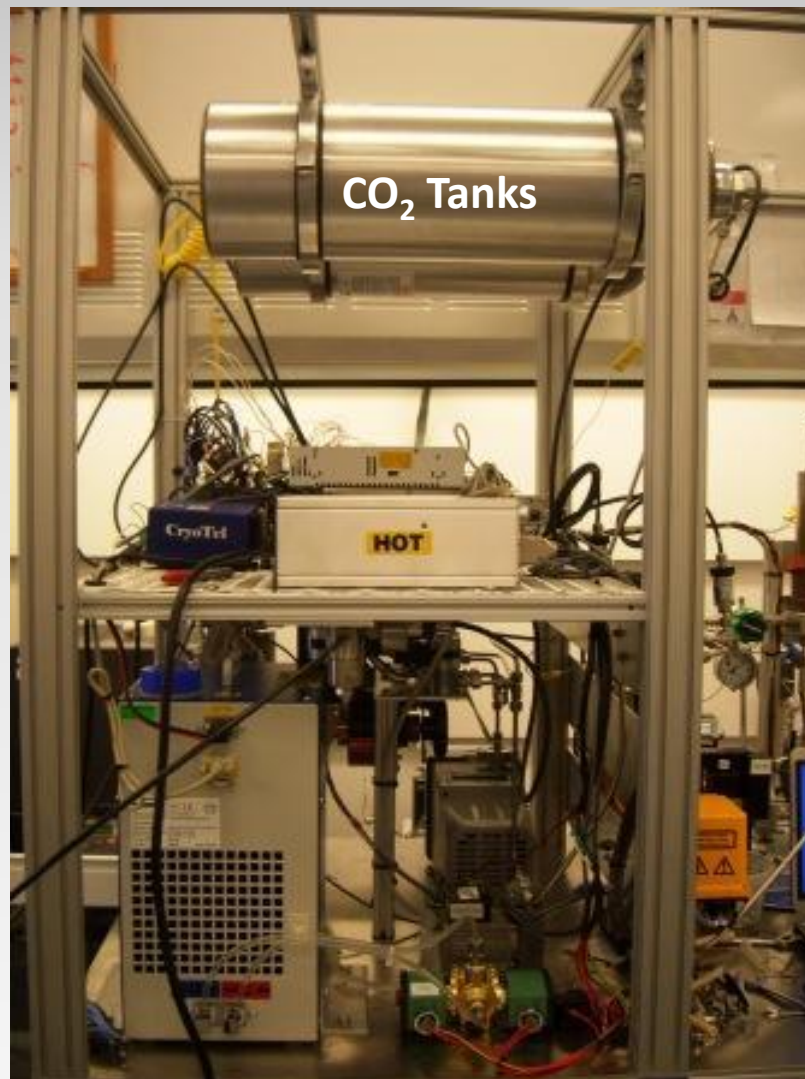
# MARCO POLO: APM



# CO<sub>2</sub> Freezer



Copper Cold Head

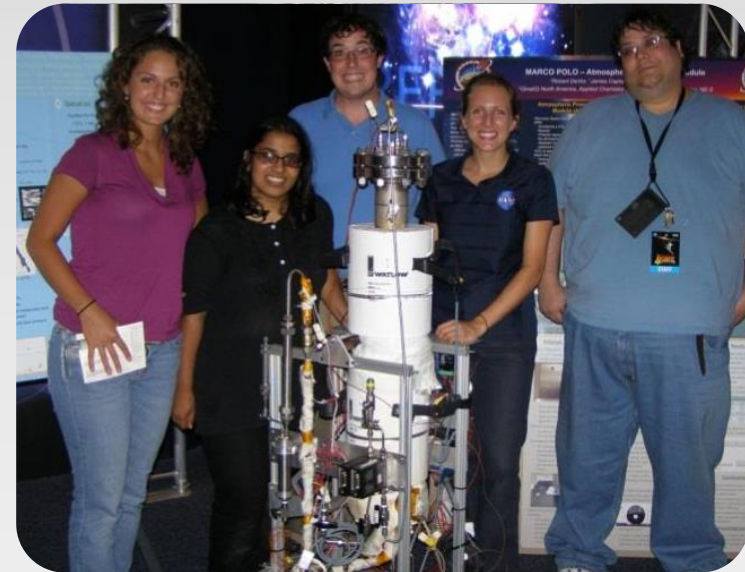




# Trash to Gas



- ❑ The Trash to Gas project is a three-year study meant to develop promising trash processing technologies for future spaceflight missions
- ❑ Years one and two focused on developing five different technologies and selecting the most promising from among:
  - ❑ Catalytic Wet Air Oxidation
  - ❑ Incineration/Gasification
  - ❑ Ozone Oxidation
  - ❑ Pyrolysis
  - ❑ Steam Reforming
- ❑ Year three is focused on refining the most promising technology



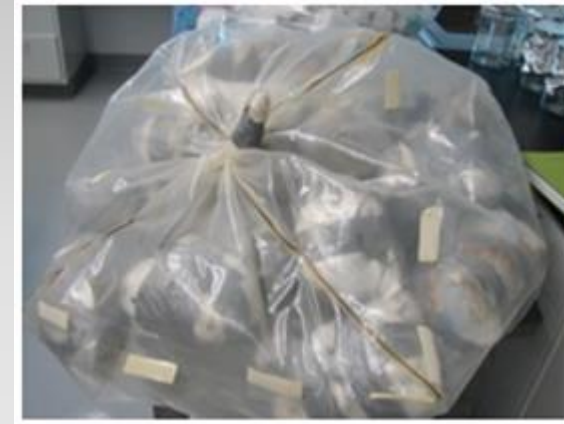
**Incineration/Gasification Team at Kennedy Space Center**



# Trash to Gas Benefits



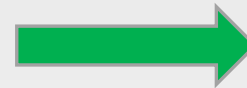
- ❑ Stabilization of all combustible waste, including human wastes
- ❑ Volume reduction of stored waste
- ❑ Production of water for life support and/or propellants



Shuttle mission waste

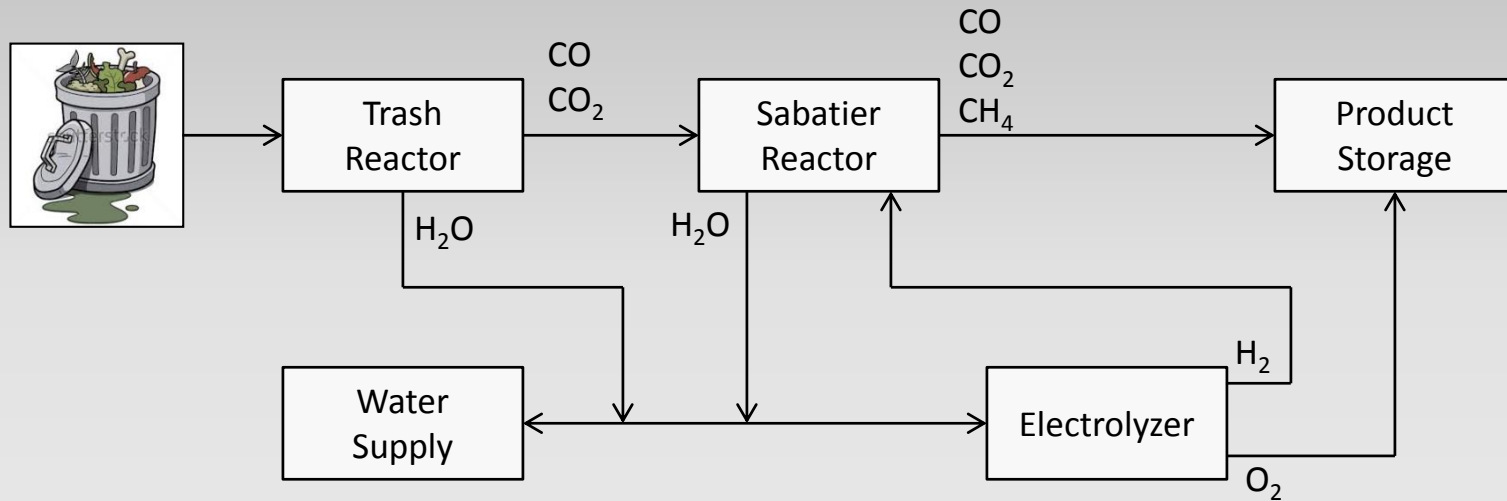


Food waste 'football'

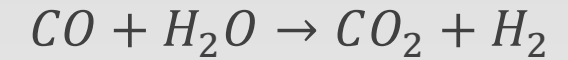
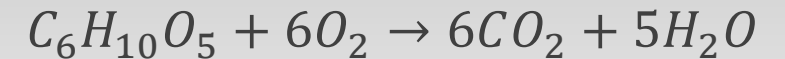


Oxygen  
Water  
Methane

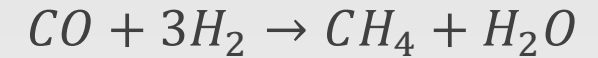
# Trash to Gas Benefits



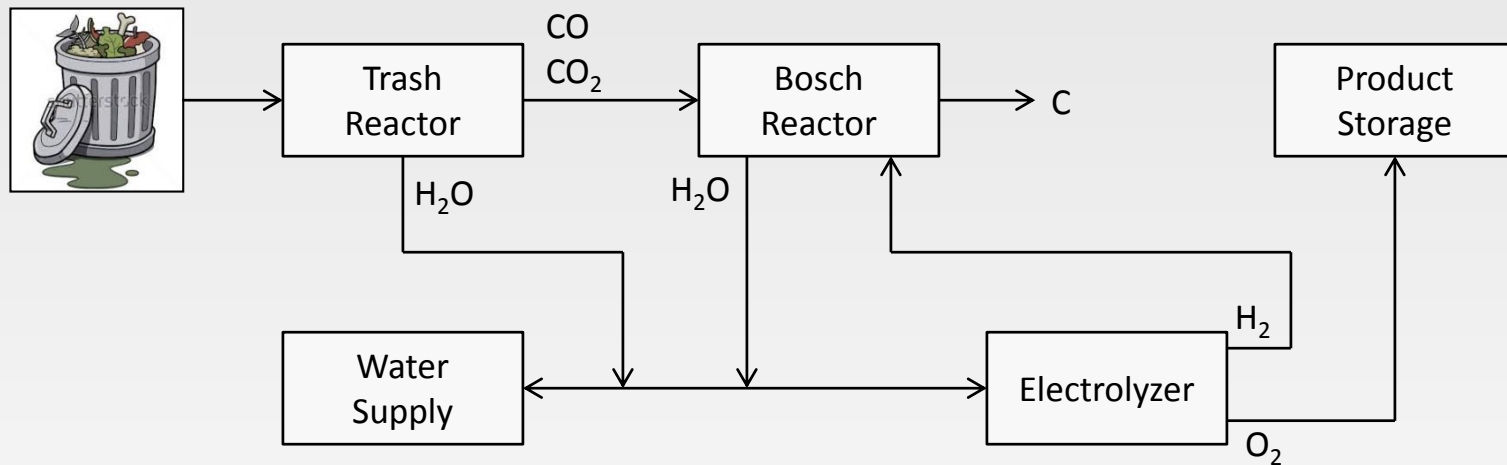
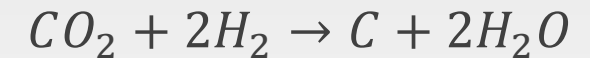
## Steam Reforming



## Sabatier/Methanation Reaction

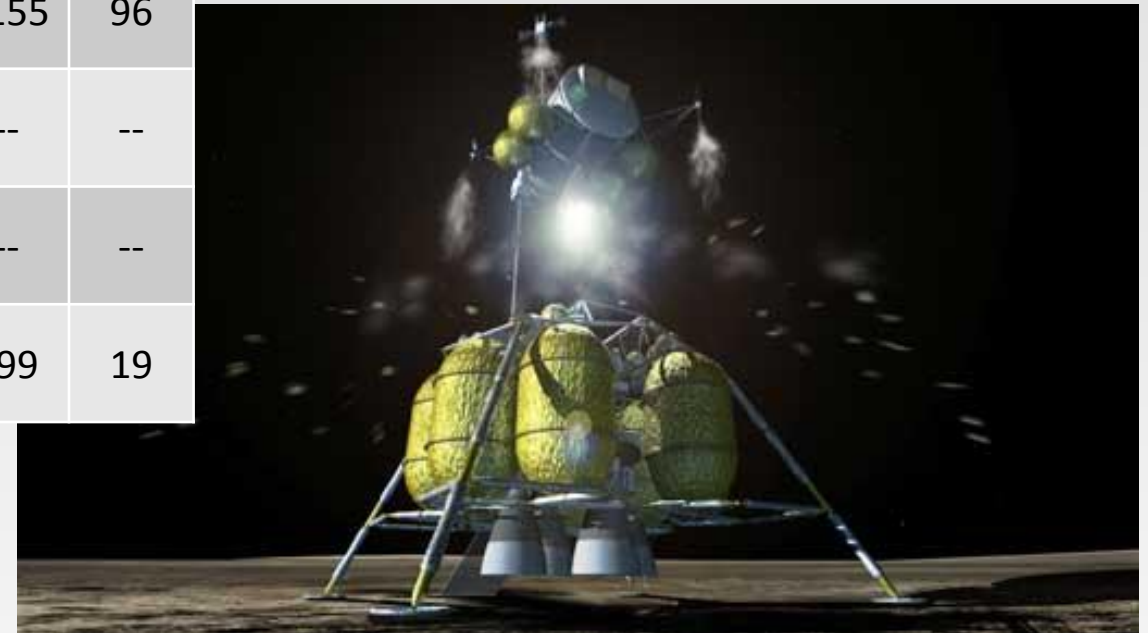


## Bosch Reaction



# Trash to Gas Benefits

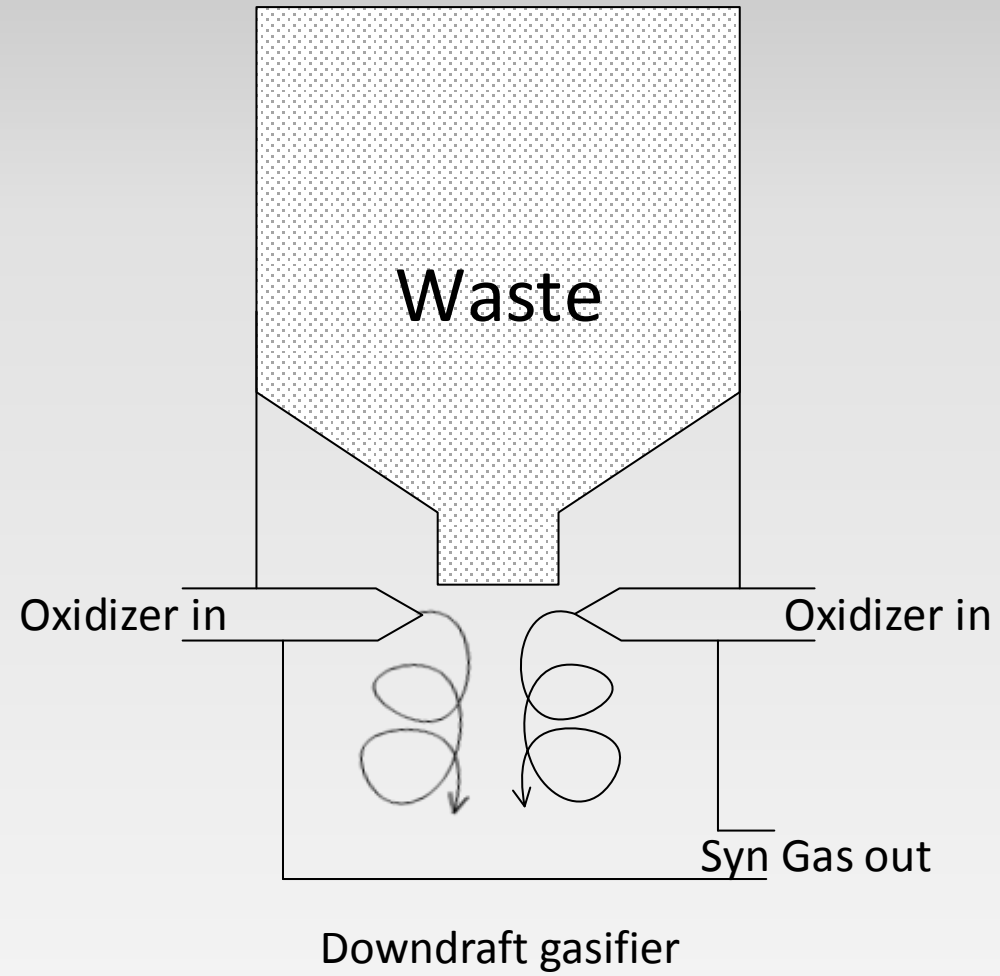
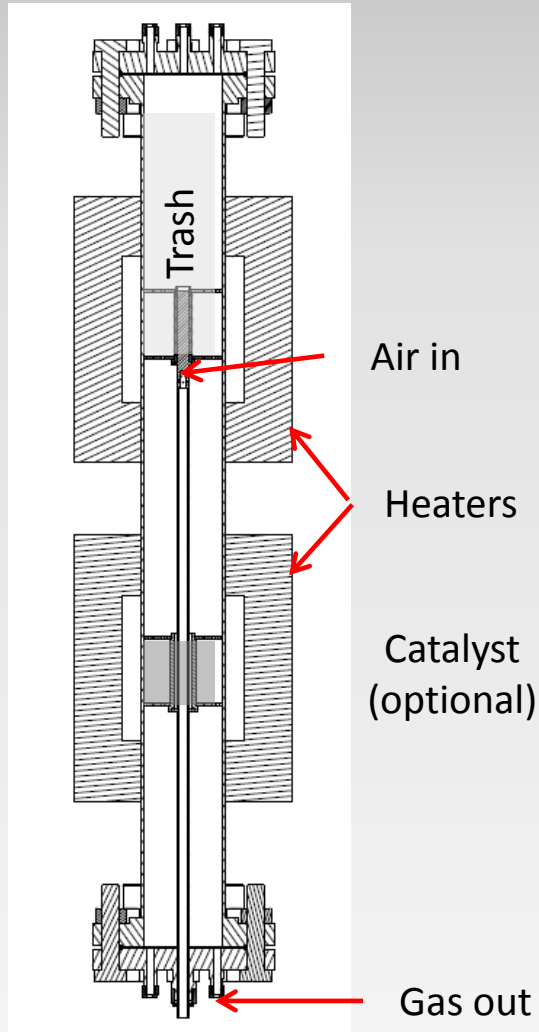
	Amount produced (+) or consumed (-), kg/yr						
	CH <sub>4</sub>	CO <sub>2</sub>	CO	O <sub>2</sub>	H <sub>2</sub> O	C <sub>solid</sub>	H <sub>2</sub>
<b>Case 1 with Sabatier (maximize water recovery)</b>	870	922	586	0	267		
<b>Case 1 with Bosch (maximize water recovery)</b>	--	--	--	--	3087	1155	96
<b>Case 2 (maximize methane production)</b>	1539	--	--	2317	-1210	--	--
<b>No Conversion of solid waste with Sabatier</b>	302	630	--	--	-127	--	--
<b>No Conversion of solid waste with Bosch</b>	--	--	--	--	1069	399	19



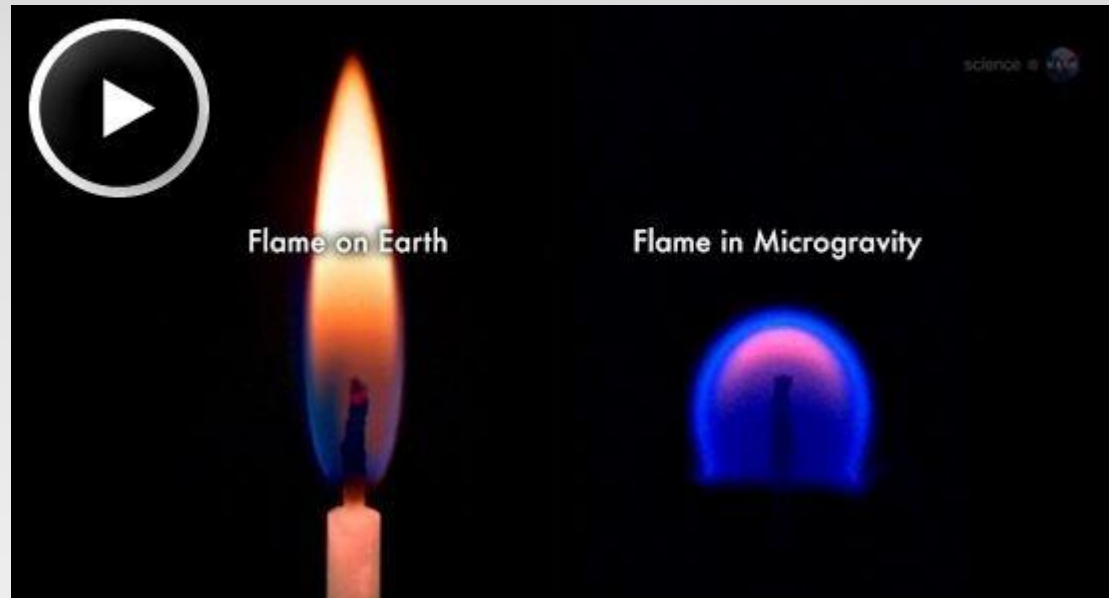
# Trash to Gas: Microgravity Challenges



KSC Reactor



# Trash to Gas: Microgravity Challenges

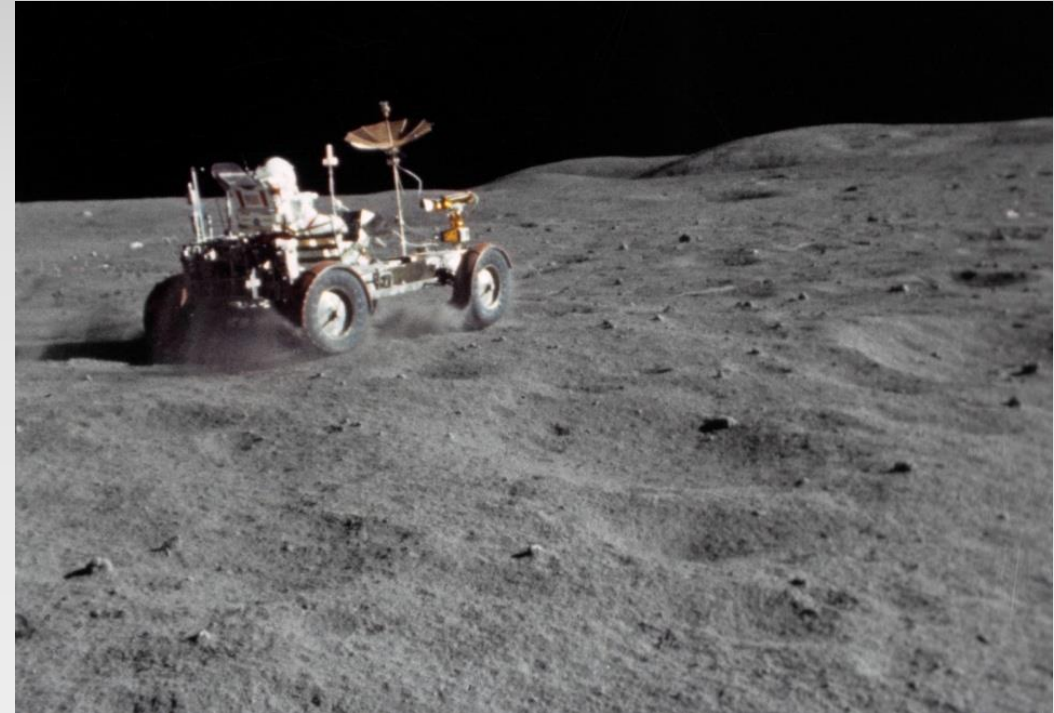




# Building Materials in Space

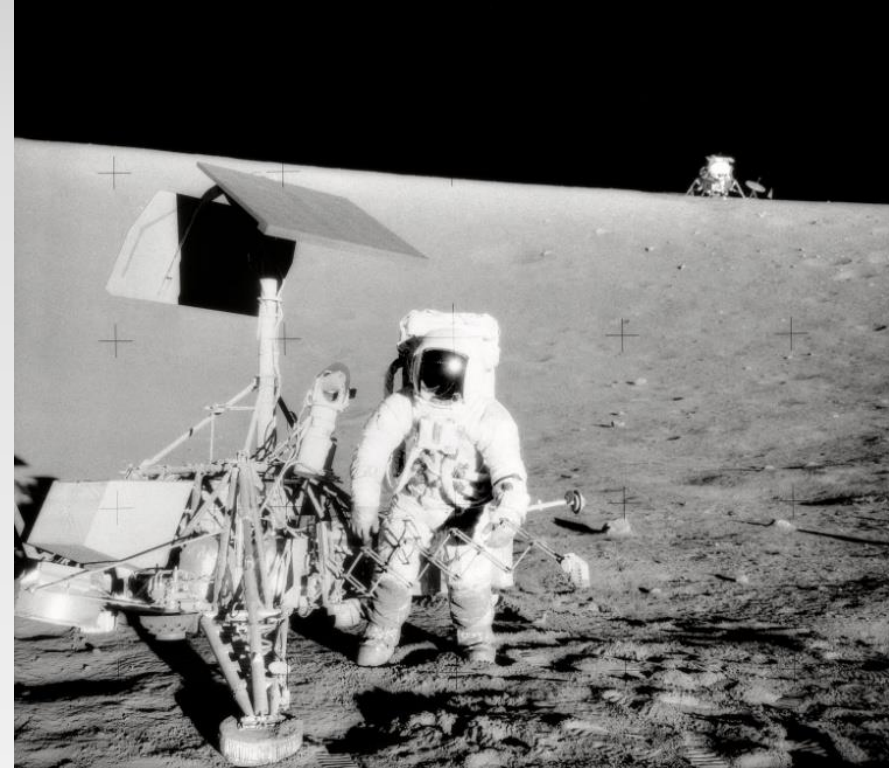
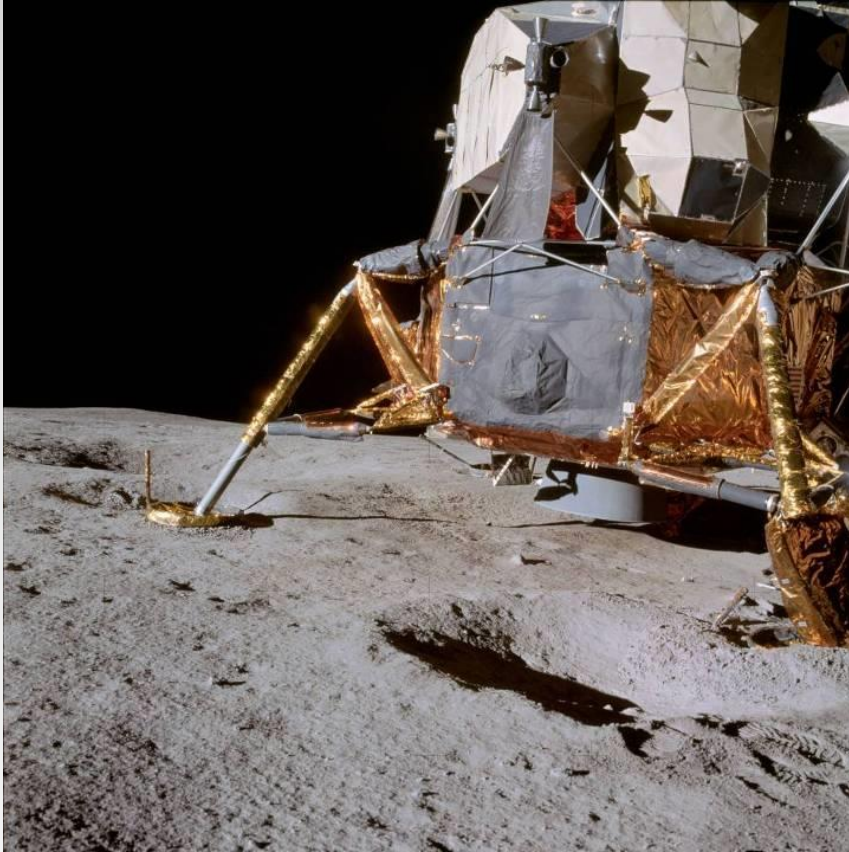


- ☐ Dust ejecta during lunar launch/landing can affect visibility, erode nearby coated surfaces and get into mechanical assemblies of in-place infrastructure
- ☐ Dust mitigation will be necessary for certain areas of the lunar habitat
- ☐ Surface stabilization can be used for roads, launch pads and other dust free areas



John Young, Photo S72\_37002

# Building Materials in Space



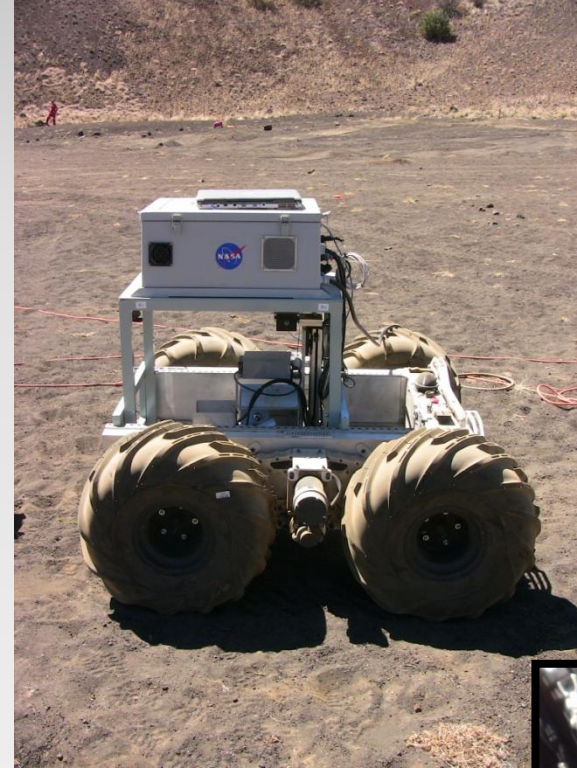
Charles Conrad Jr. and Surveyor III



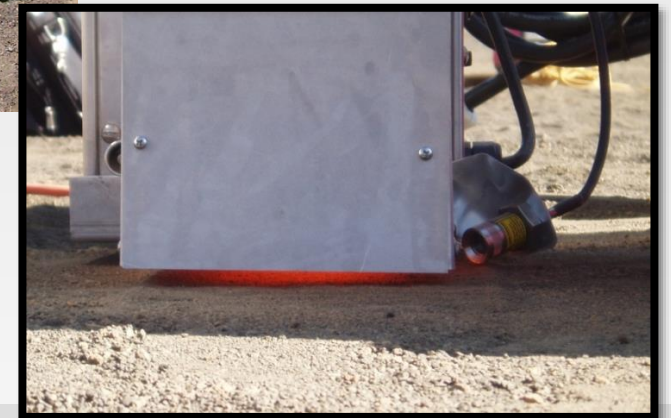
# Building Materials in Space



Cave in Hawaii used for shelter



Large Area Surface  
Sintering System  
(LASSS) used to sinter  
the volcanic soil in  
Hawaii

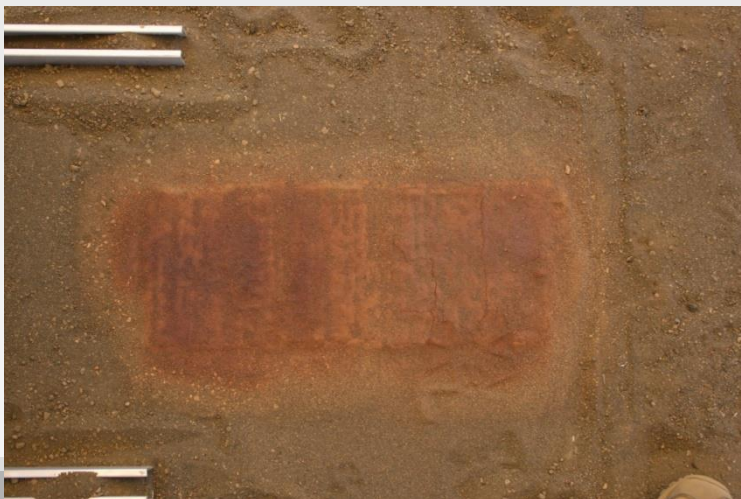




# Building Materials in Space

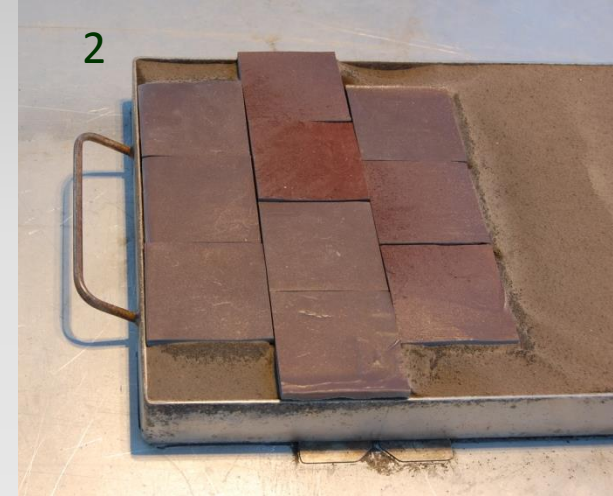
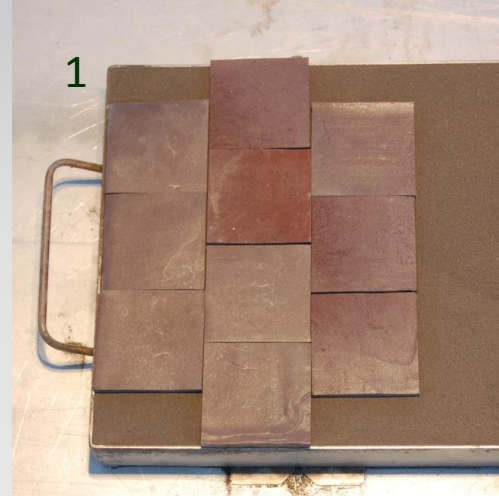


- ☐ Able to layer tephra and connect sintered areas
- ☐ Strengths from 30 – 240 psi
- ☐ Fired thruster on sintered area
- ☐ Environmental conditions caused issues



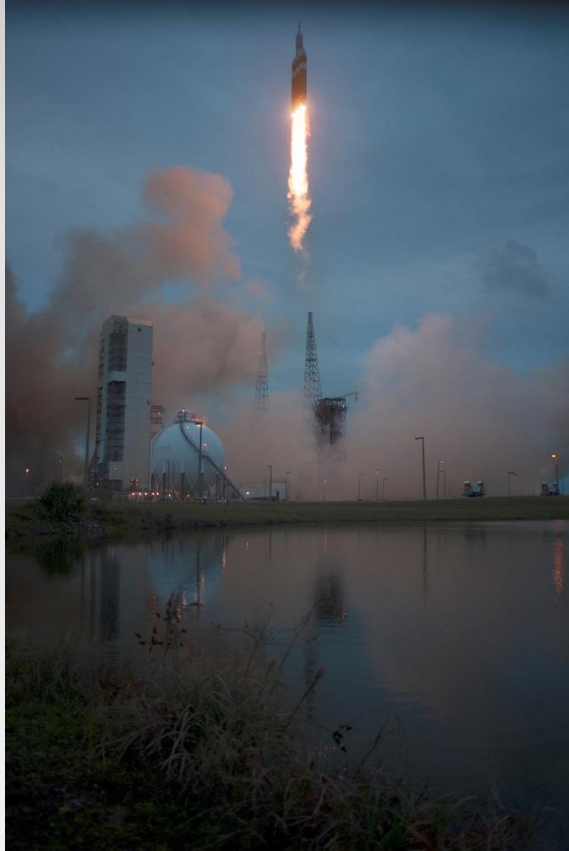


# Building Materials in Space



# Questions?

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Orion lift off  
Photo credit: NASA/Sandra  
Joseph and Kevin O'connell



The Orion floats in the Pacific with stabilizing balloons inflated as the USS Anchorage moves in to retrieve the spacecraft.